Chapter 5

Research, Documentation, and Testing

Starting a Search

The matrix cannot work its magic alone. A group of ideas cannot be ranked against project specifications until something is known about each of idea. Although identifying constraints and generating alternative solutions are group efforts, research—reading the literature, gathering data by telephone and direct contact—requires team members to work individually or in pairs and to report their findings back to the group. Many research questions can be answered by students who are absent from school for reasons but not incapacited by illness.

When supervising student research, three broad questions are essential to keep in mind:

What is the current state of the art for any given idea? Who manufactures similar products? For a solution to be innovative, teams must know whether an idea is already on the market, and, if it is, how well it solves the defined problem.

Who is the target user of this product? Who would be willing to pay for it? Whether a team is redesigning a traffic intersection or building a device to aid stroke victims, someone or some agency is the customer. If a team wants its solution to be practical, the ideas can't be ranked until the market is understood.

How would this product work? How can this device be tested? Whatever the field of inquiry, a team must know exactly how to make sure its ideas are feasible. An idea can't be ranked until team members know how it works and how it can be tested.

Thus, before any idea can be effectively ranked on the matrix, the team must gather sufficient data to identify

- the current state of the art
- the market potential
- procedures for testing

This phase of the research is extremely important. Many students come to the matrix predisposed toward a particular idea—sometimes consciously, sometimes unconsciously. Without the team carefully researching all ideas, a dominant personality can sway others to a "pet" idea. Often teams are so eager to get to the actual construction phase, they don't want to consider a lot of options. An exceptional group of students may slight this phase and still produce an exciting solution, but for the process to work for all students, careful consideration of each idea will assure each team member that the solution the whole team chooses is, after all, the best one possible.

First Round of Research

When students establish personal contacts through mentoring, they put themselves in a position to obtain superior assistance in the research process. Students need to know that business and professional people, however much they might want to be helpful, do not want to—and often will not—spend time answering trivial questions. Before contacting a mentor, students will need to do the "book work" and "leg work" that make questions posed to their mentors intelligent.

The first stop for research, as suggested earlier, is the school library. A librarian trained to field naive questions can direct inquirers to resource materials for beginning the data-gathering process. An up-to-date general encyclopedia may be a good first stop. Even better, there are scientific encyclopedias, such as the McGraw-Hill *Encyclopedia of Science and Technology* or the Kirk-Othmer *Encyclopedia of Chemical Technology*. All encyclopedias have bibliographies, which students can use to find other reference works and textbooks in the field. Periodicals—technical reports, conference proceedings, journals and magazines—may offer the latest information in any field of science or technology. A librarian can assist a student in sorting through the different periodical indices, such as Reader's Guide, Applied Science and Technology Index, Physics Abstracts, Electrical and Electronics Abstracts, or Engineering Index, and finding those appropriate to the student's level and research need.

Students in high schools with access to the Internet may be able to use college or university online catalogs, compact disc products, or remote databases. If the school is not online, teachers may be able to negotiate with a college library to allow selected students to use the college's network. With good access to the Internet, students can post inquiries on a variety of bulletin boards or browse information in the multitude of databases that inhabit the World Wide Web.

A Yellow Pages Directory and a telephone can be powerful tools for finding out what local companies exist in the field of inquiry and what products they make. To identify manufacturers and suppliers nationwide, students can consult the Thomas Register, which is organized by products and services, and company profiles, with a catalog file for specifications, illustrations, and the performance data of products.

Federal or state government agencies, such as the Departments of Energy, Forestry, Fish and Waterways, or Transportation, can be contacted either by e-mail or telephone. NASA, for example, offers information materials for use in schools. The offices of legislative representatives, especially those representing the district in which a school is located, can assist students in opening doors.

As students move from resource books through telephone and e-mail conversations to questioning mentors, they become increasingly expert in their field of inquiry. They not only become conversant in details of a field, they also come to feel the power of knowing what they are talking about.

Patent Searches

A patent grants to an inventor the exclusive right to market an innovative device or process. It applies to the United States and its territories and possessions. To acquire a patent, an invention must meet three criteria:

- novelty
- usefulness, that is, it must function
- non-obviousness, that is it must improve upon the state of the art

Patents are granted for processes, machines, manufactured items, compositions of matter, varieties of plants, and ornamental designs, among other things. A functional patent is good for 17 years, a design patent for 14.

The U.S. Patent and Trademark Office (U.S.P.T.O.) issues an *Official Gazette* that lists all new pending patents. Students with access to this publication can look up devices similar to those they are proposing by checking under the device's function. For example, a team designing a new thermometer would check for similar instruments under "temperature-measuring device."

There are a number of avenues for doing patent searches. Every state has at least one Depository Library, which maintains a microfilm collection of all issued patents, the *Classification Manual* which explains the Patent and Trademark Classification System, and a computer supplied with the classification system program. Although the microfilm may not list patents earlier than 1973, it is a good place to start understanding the subject area.

Some libraries can access commercial computer databases, such as Dialog or LEXIS, which students can also use for patent searches. At Dartmouth's Feldberg Library, a computer CD-ROM allows searches by key words, inventors' names, companies to which patents have been issued, or words in the title of the patent abstract. Some business firms have the same capacity. Again, teachers need to negotiate permission for students to gain access to such resources.

The Internet has several locations where students can search patents. The U.S.P.T.O. is online at

http://www.uspto.gov

An IBM-created database offers access to patents, both descriptions and images, and allows searchers to move backward or forward through the database to search the history of a particular patent.

http://patent.womplex.ibm.com

Teachers whose students are designing novel devices may want to enlist a patent attorney to serve on the review board and perhaps offer to advise students as to whether their invention is patentable. Students of Lynn Godshall gathered information from attorneys listed in the section in Popular Mechanics called "For Inventors." Godshall cautions that some patent attorneys may ask students to send them their ideas. To protect students, he makes sure they understand the process of "witness and understanding," which verifies that an idea is their own and which can be executed at their oral presentation, provided the log or project notebook contains the idea and its date of inception. The oral presentation is equivalent to a public disclosure of the students' idea; they have one year from the date of the presentation to apply for a patent.

A free publication, "Basic Facts About Patents," is available from the U.S.P.T.O; a more complete booklet, "General Information Concerning Patents" is available at cost from the U.S. Government Printing Office.

Market Research

Some market research can be done in a library. For example, the government issues a *Statistical Abstracts of the United States* which contains data relating to American society from demographic, economic, and cultural perspectives. Most market research means going out into the field and talking to people. Nancy Borchers' geometry students, in Cincinnati, Ohio, designed surveys to determine both the shape of the cookies they wanted to design and the ingredients.[11] Tony Komon's physics students, in Niskayuna, New York, talked to arthritic neighbors and residents of nursing homes before designing devices for the elderly; a team that invented an arm-bike interviewed a paraplegic and her neurologist.[12] When students interact with community people, they see ways in which the world of the classroom is connected to the world outside. Before sending students into the field, though, teachers may want to conduct marketing exercises to help them understand what they are seeking.

It surprises students to realize that markets *do* exist. Who would be interested, for example, in an energy-efficient dog door? Through market research, a group of Dartmouth students found that several groups were, including pet store managers and builders of energy-efficient homes.

Market Segmentation

When determining the market for a product, the question,

> Who is the customer?

may seem too vague to answer. Segmentation lets students move from the amorphous to the definite. A classroom exercise in market segmentation allows students to imagine an ideal customer. Questions about the target customer might include the following:

> How old is this person?
> Which gender?
> What economic status?
> What kinds of magazines does the person read?
> What kind of job?
> Where does she or he shop for clothes or groceries?

The goal of the exercise is to make the description of the ideal customer so specific that students would recognize this person on the street. From the particular, the students can expand to define a whole group which is their marketing target.

Harry Stuckey, of East Rockaway, New York, likes to start off his physics students with an exercise in market segmentation. After eliciting a number of opposites, he asks the class to create the ideal customer by choosing one of each pair of antonyms. For example, the list might begin with these pairs:

> tall/short
> female/male
> old/young
> educated/not educated
> urban/rural
> employed/unemployed
> newspaper reader/newspaper non-reader
> computer user/computer non-user

A target customer then might be defined as:

> A young, tall, married female who was educated at Dartmouth. She is employed, jogs, goes to church, lives in the country, and reads the *New York Times* and *Wall Street Journal*. She works on a computer but has carpal tunnel syndrome.

Stuckey continues the exercise by eliciting ideas for this client's typical Saturday morning. Once the class had decided that the target customer likes to "jump into the hot tub, read the paper, and eat breakfast while listening to National Public Radio," they are primed to identify a problem their hypothetical person might have which they themselves could solve.

11. See "Interdisciplinary Geometry," p. 90.
12. See "Project Work on Ten Minutes a Day," p. 88.

Surveys and Interviews

As teams go to work on projects, members take responsibility for contacting potential customers. If the team is inventing something for arthritics, the market researchers interview people with arthritis, as well as medical personnel who work with arthritic patients. If the project is designing toys for first graders, a trip to a first-grade classroom is in order. If students are redesigning a traffic intersection, visits to the township office or the state department of transportation can yield data on automobile accidents, traffic density, and about drivers and others who use the intersections. A "trial run" of a survey or questionnaire, using a dozen or so respondents, can help students recognize overly broad or unclear questions which they will need to refine before taking the survey public.

Just as students need to be informed about their subject and to have specific questions when they contact mentors, they need similar preparation for interviewing potential customers. They also need to be both patient and persistent. In the world beyond the classroom, information is not always attainable at a moment's notice. When they find themselves obstructed at one point, young people can learn how to move politely around the obstacles to get the information they need.

As teams iterate the problem-solving cycle, they may find themselves returning again and again to their potential customers. A first round of interviews helps the team narrow the field of alternative ideas; a second round helps it to focus on desired features that then become design specifications. As the team gets closer to its final product, students will know their customers well enough to design an effective advertisement to use as a final review prop.

Talking with the people for whom a solution is being designed engages a student's affective intelligence. The team finds out in a very direct way how its solution can make a difference. Talking to potential customers may prevent students from pursuing solutions for which no problem exists. Further, potential customers who have been consulted may be more likely to adopt a solution or new device when they feel they have been included in the design process.

Test Protocol

Scientists and engineers initiating new processes or designing new devices need to know whether their ideas are workable. They may need to do research on testing devices and find out what equipment is available that meets testing criteria. They may even need to invent a whole new apparatus in order to perform effective evaluations. For an engineer, it is not enough to say, “It works.” “It works” must be qualified: under what conditions does it work? How long will it work? The question, “How do you know what you know?” must be answered with measurements and hard data.

The energy-efficient dog door designed by a team of Dartmouth students was not nearly so impressive as the wind tunnel they built to test its effectiveness. They had pursued a number of potential test designs, such as measuring the temperature differential between the outer and inner doors, but could not find an effective method of evaluation. Then, one evening, several students observed that a door cracked open on the ground floor of a house created a considerable draft, enough to lift tissue paper 90 degrees, while a door cracked on an upper floor did not. They began to study the relationships among air flow, air pressure, and heat transfer. Eventually, they designed a test that allowed them to measure the pressure differential, instead of the heat differential, between the two sides of the dog door. By the time they finished constructing a wind chamber to test their prototype along with several manufactured doors, they had come to a deep understanding of the laws of thermodynamics.

Not all testing requires specially designed equipment. Physics teacher Tom Woosnam encourages students to find reasonable methods for testing, whether in a laboratory or in the field. A group designed a bicycle brake that adjusted itself according to weather conditions, using spring scales to test the force exerted on a cable. Another group, after devising a set of bicycle brake-and-turn lights, lent its prototype to friends and to a San Francisco bike messenger for trial runs. A third group modified a wheelchair to prevent patients from getting up without applying the brakes; patients at the local hospital gave the design rave reviews.

Testing is an important part of building a prototype. Even when students design solutions, rather than construct physical devices, they need to think about how their designs can be evaluated in real life.

The Paper Trail

Good problem solvers keep notes. A "paper trail" of the process assures a team that blind alleys are never a waste of time, but, rather, that they can make clear why a particular idea doesn't work. Documenting ideas that don't work is as important as documenting those that do. Information from failed attempts builds the knowledge base from which success rises.

Work Logs

A Work Log or Project Notebook documents the decision-making process of the project. It should include details of data gathering, brainstorming lists, matrix analyses and outcomes, who performed which tasks and what problems they encountered. Logs should be clear and detailed enough for someone outside the group to follow the steps which led to the selection of a specific problem, the analysis of alternative solutions and final selection, and the execution of the final design.

Some teachers schedule time during class in which students summarize their log, evaluate their progress, and outline tasks of the coming week. A weekly or daily summary, signed by each team member, can be handed in, so that the teacher can track the team's progress. The actual Work Log remains with the Team Secretary or in the classroom.

Reviewing the Work Log on a regular basis, teachers can write their comments, questions, and suggestions for the team. These provide a written record of the teacher's input for the project and let students and teachers check back over earlier questions to see whether the team has effectively addressed them in their latest design. The teacher's notes also save the teacher valuable time during the review process.

Written Reports

Reports are a way for students to formalize findings and communicate ideas to an audience beyond the teacher. Lengthy projects may require one or more progress reports, as well as a final report that will coincide with the formal review (see page 71). Having students hand in their written reports a few days before the oral presentation gives teachers and review board members a chance to preview the proposed solution and prepare questions. Limiting the number of pages of final reports, even docking points from teams that exceed those limits, prevents the report from becoming interminable and helps students learn to be concise.

Inviting an English-teacher colleague to collaborate in class on report writing can help both teachers and students. Karen Falkenberg brought in colleague and English teacher Jeff Walkington to spend time discussing the art of technical writing. Walkington asked the students to consider their audiences—the executive (or decision-maker), the scientist (or expert), the technician (or operator), the layperson (or consumer). "The primary audience for a student team's report," added Falkenberg, "is the teacher (or evaluator), which means that students' reports often need to include explanations of concepts underlying a project."

A good progress report includes diagrams of devices or plans and explanations of the concepts or principles used. Some reports include the process—a chronological description of team efforts, the matrices used to analyze different aspects of the problem, the reasoning behind each decision, even test procedures that didn't work. Other reports, in particular the final ones, are a comprehensive description of the problem and its chosen solution without details of the process.

Final reports are usually divided into three sections: the front matter, the body of the report, and the back matter. The front matter includes:

- the title page
- an abstract of the problem solved
- the table of contents
- a list of illustrations

The body of the report includes:

- a brief description of the problem
- an explanation of the cause of the problem and the reason for seeking a solution
- if the solution is an invention, a brief description of the state of the art
- a list of specifications, with the key specs prominent
- a brief description of alternative solutions not pursued
- an analysis of the alternatives, with justification of the chosen one
- a detailed description of the solution (and prototype)
- a description of the test results and analysis
- discussion and conclusions, with recommendations for the future of the project

The back matter includes:

- a bibliography
- appendices that detail the chronology of the project and its budget

Portfolios

Keeping a portfolio for each group helps document the students' progress. For long-term projects, which require several reports, a portfolio makes informal assessment of team progress easy.

Each page of the Work Log can be used to give immediate (in-class) feedback to students. It also becomes a document in the portfolio that can be used later for assessment. Each report can be matched with the Work Log to make sure the project is on track. At the end of the project, the portfolio is there to explain how any grade is determined. It is also tangible evidence that demonstrates the efficacy of the engineering approach to problem solving—to a school board member, a potential review board member, or colleagues at a professional meeting.

In long-term projects, teachers want to be able to see the progress and to make sure that questions they have noted on one of the project reports are answered in the next one. The key, according to Lisa Torres, of Lebanon, New Hampshire, is not to fall behind: keeping everything—work logs, lab notes, written reports—in the classroom assures that at any time information about a project can be located by either the teacher or the students.